Application of the dynamic factor analysis for abundance indices estimated from the multidisciplinary groundfish and shrimp research survey conducted in the Estuary and northern Gulf of St. Lawrence

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APPLICATION OF THE DYNAMIC FACTOR ANALYSIS FOR ABUNDANCE INDICES ESTIMATED FROM THE MULTIDISCIPLINARY GROUNDFISH AND SHRIMP RESEARCH SURVEY CONDUCTED IN THE ESTUARY AND NORTHERN GULF OF ST. LAWRENCE

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ABSTRACT

Grégoire, F. 2013. Application of the dynamic factor analysis for abundance indices estimated from the multidisciplinary groundfish and shrimp research survey conducted in the Estuary and northern Gulf of St. Lawrence. Can. Tech. Rep. Fish. Aquat. Sci. 3022: vi + 27 p.

Dynamic factor analysis (DFA) was applied to 21 time series of abundance indices from a multidisciplinary groundfish and shrimp survey conducted annually in the Estuary and northern Gulf of St. Lawrence. Sixteen different models were tested on these indices. The optimal model allowed the detection of three common trends as well as the series of species or taxa associated with these trends. DFA also revealed a relationship between some of these series and the volume of the cold intermediate layer (CIL; water < 0°C). A chronological clustering analysis of the same series of abundance revealed the presence of significant cut-offs or changes in the ecosystem of the Estuary and northern Gulf of St. Lawrence.

RÉSUMÉ

Grégoire, F. 2013. Application of the dynamic factor analysis for abundance indices estimated from the multidisciplinary groundfish and shrimp research survey conducted in the Estuary and northern Gulf of St. Lawrence. Can. Tech. Rep. Fish. Aquat. Sci. 3022: vi + 27 p.

L'analyse dynamique factorielle (DFA) a été appliquée à 21 séries temporelles d'indices d'abondance provenant d'un relevé multidisciplinaire aux poissons de fond et à la crevette conduit annuellement dans l'estuaire et le nord du golfe du Saint-Laurent. Seize modèles différents ont été testés sur ces indices. Le modèle optimal a permis de détecter trois tendances communes de même que les séries d'espèces ou de taxons associées à ces tendances. DFA a aussi permis de relier certaines de ces séries au volume de la Couche Intermédiaire Froide (CIF; eaux < 0 °C). Une analyse de groupement chronologique appliquée sur ces mêmes séries d'abondance a mis en évidence la présence de coupures ou de changements importants survenus dans l'écosystème de l'estuaire et du nord du golfe du Saint-Laurent.

1. INTRODUCTION

Dynamic factor analysis (DFA) is a technique that detects common trends in time series (Zuur et al., 2003a; 2007). This technique also determines which series are most strongly linked to these trends and the possible relationships between these series and explanatory variables. The mathematical details of the dynamic factor analysis are presented in Zuur et al. (2003a). DFA has been used in econometrics (Harvey, 1989), in psychology (Molenaar, 1985; Molenaar et. al., 1992), and for the first time, in fisheries by Zuur et al. (2003b) and Zuur and Pierce (2004). DFA has also been applied to fishing data by Erzini (2005) and to abundance data on marine species by Erzini et al. (2005), Chen et al. (2006), Azavedo et al. (2008), Chen (2010), Gaertner (2010), and Ligas et al. (2011). In these studies, the main explanatory variables were surface water temperature, North Atlantic Oscillation (NAO), freshwater runoff, an upwelling index, and the amount of precipitation.

In this study, DFA was applied to time series of abundance indices. The first two objectives of the study involved identifying common trends in these series and determining which series are linked to each trend. The last objective was to explore possible relationships between the abundance indices and two explanatory variables.

2. MATERIAL AND METHODS

2.1 Data source

DFA was applied to 21 time series of abundance indices of fish species or taxa from a multidisciplinary groundfish and shrimp survey conducted annually in the Estuary and northern Gulf of St. Lawrence (Bourdages et al., 2010). The surveys used for this study cover the period from 1990–2009 (N=20), and the species or taxa of fish chosen are those that were correctly identified throughout this period. The abundance of species or taxa was expressed in mean weight (kg) and in mean number per standard 15-minute tow (Appendices 1 and 2). To be considered valid, tows must be between 10 and 20 minutes in duration (± ⅓ of the target duration). The species chosen include capelin's (*Mallotus villosus*) four main predators (Savenkoff et al., 2004): Atlantic cod (*Gadus morhua*), American plaice (*Hippoglossoides platessoides*), Greenland halibut (*Reinhardtius hippoglossoides*), and redfish (*Sebastes* spp.). However, capelin, which is a pelagic species, was left out of the study. Only the presence-absence data for this species is used to calculate a dispersion index (Grégoire et al., 2002).

Two explanatory variables were analyzed: the average temperature (°C) of the cold intermediate layer (CIL) and the volume of CIL water (km^3) less than 0°C. The technique used to calculate CIL temperatures was presented by Gilbert and Petitgrew (1997) and the temperature and volume data were taken from Galbraith et al. (2009). The volume data relate to oceanographic regions 1 through 7, inclusively (northern Gulf of St. Lawrence and Cabot Strait) (Galbraith et al., 2009).

2.2 Dynamic factor analysis

The dynamic factor analysis model can be expressed as follows:

$$y_t = Az_t + Bx_t + e_t$$

where y_t represents a matrix of N time series of abundance index values at time t; z_t represents a matrix of M common trend values at time t; A is a matrix of weighting factors of a dimension of N × M; x_t is a matrix containing the values of the explanatory variables; B is the regression parameter for each explanatory variable; and e_t is the error term.

The value and sign of the weighting factors of A determine how the time series relates to the trends. The regression parameters indicate how the explanatory variables impact the time series. These parameters are significant at the 5% level for a t statistic of 2.101 (df=18). The model assumes that $e_t \sim N(0,R)$, where R is the error covariance matrix. Two types of R matrices can be modelled: (1) a diagonal matrix and (2) a non-diagonal symmetric matrix. The elements of the latter represent information that cannot be explained by common trends or explanatory variables. In this study, only the diagonal matrix was used because the number of time series of abundance indices (21) was greater than the number of years (20).

Several models have been tested based on standard mean weight (kg) (Table 1A) and mean numbers per tow (Table 1B) using version 2.6.6 of the Brodgar software (Highland Statistics Ltd., http://www.brodgar.com). Zuur et al. (2003a) recommend using Akaike's information criterion (AIC) to select the best model. AIC is defined as the difference between the measure of fit (maximum likelihood) and the number of parameters of a model (number of trends, number of explanatory variables, and the structure of R). In this study, the best model was that with the lowest AIC value.

2.3 Chronological clustering analysis

The application of the dynamic factor analysis to abundance data assumes that gradual changes occurred over the years. In addition to the DFA, the chronological clustering analysis (Legendre et al., 1985; Bell and Legendre, 1987; Legendre and Legendre, 1998) was used to identify periods during which time series abundance indices presented identical patterns.

The Euclidean distance was used as a means of measuring similarity, and the sensitivity of the analysis was measured using five levels of fusion (alpha = 0.01, 0.05, 0.1, 0.2, and 0.3). The lowest alpha values are associated with the most significant cut-offs and the highest values with more detailed levels of information and a greater number of cut-offs. The chronological clustering analysis was also applied using the Brodgar software.

3. RESULTS

3.1 Description of explanatory variables

The mean CIL temperatures present upward trends from 1946 to 1952, from 1961 to 1968, and from 1974 to 1980 (Figure 1A). An upward trend has been observed since the beginning of the 1990s, with sharp drops in 2003 and 2008.

The volume of CIL water less than 0°C shows a downward trend between 1991 and 2010 (Figure 1B). Higher values were recorded in 2003 and in 2008, and the lowest values of this series were recorded in 2000, 2006, and 2010.

3.2 Mean weight per tow

3.2.1 Trends and model fits

Sixteen different models were applied to the time series abundance indices expressed in mean weight (kg) per tow (Table 1A). Based on the AIC criterion, the optimal model (12) was characterized by three common trends and one explanatory variable: the volume of CIL water less than 0°C.

The model's first trend is characterized by little variation until 2003 and then by a significant decrease starting in 2004. This decrease was followed by increases in 2007 and 2009 (Figure 2A). The model's second trend is characterized by a decrease between 1991 and 1993 followed by a gradual increase until 2000. Following decreases in 2001 and in 2002, this trend varied little from 2003 onward. The third trend is characterized by a significant decrease noted from 1990 to 2000. There was little variation following this decrease until 2009. The data fitted to the model are fairly consistent with the data observed (Figure 2B), and the residuals show no particular patterns (Figure 2C). However, the entire spinytail skate (*Bathyraja spinicauda*) (code s102) time series is characterized by residuals of close to zero. This species is not very abundant and began to be observed from 2005 (Appendices 1 and 2).

3.2.2 Loading factors

As suggested by Zuur et al. (2003b), an arbitrary cut-off level of 0.2 (in absolute value) was used to determine which abundance series was associated with each trend. Spiny dogfish (*Squalus acanthias*) (s24), smooth skate (*Malacoraja senta*) (s91), and sandlance (*Ammodytes* spp.) (s696) are positively related to the first trend, while spinytail skate (s102), Atlantic herring (*Clupea harengus harengus*) (s150), silver hake (*Merluccius bilinearis*) (s449), and Atlantic halibut (*Hippoglossus hippoglossus*) (s893) are negatively related to this trend (Table 2A; Figure 3A). Thorny skate (*Amblyraja radiata*) (s90), smooth skate (s91), winter skate (*Leucoraja ocellata*) (s100), Atlantic cod (s438), haddock (*Melanogrammus aeglefinus*) (s441), longfin hake (*Urophycis chesteri*) (s444), white hake (*Urophycis tenuis*) (s447), American plaice (s889), witch flounder (*Glyptocephalus cynoglossus*) (s890), yellowtail flounder (*Limanda ferruginea*) (s891), and Greenland halibut (s892) are positively related to the second trend (Table 2A; Figure 3B). Two species are negatively related to this trend: pollock (*Pollachius virens*) (s443) and winter flounder (*Pseudopleuronectes americanus*) (s895). Four species are positively related to the third trend: haddock (s441), longfin hake (s444), white hake (ss447), and redfish (s792) (Table 2A; Figure 3C). Only one species is negatively related to this trend: Greenland halibut (s892). Finally, black dogfish (*Centroscyllium fabricii*) (s27) is not related to any of the trends. The species with the highest positive loading factors for each trend are shown in Figures 4A, 4B, and 4C. These series present annual variations similar to the corresponding trends.

Some of the abundance series are related to only one trend. This is the case with spiny dogfish (s24), spinytail skate (s102), Atlantic herring (s150), silver hake (s449), sandlance (s696), and

Atlantic halibut (s893), which are only related to the first trend, either positively or negatively (Figure 5A). Eight species are only associated with the second trend: thorny skate (s90), winter skate (s100), Atlantic cod (s438), pollock (s443), American plaice (s889), witch flounder (s890), winter flounder (s895), and yellowtail flounder (s891). Lastly, one species is only associated with the third trend: redfish (s792). Smooth skate (s91) is related to the first two trends, and haddock (s441), longfin hake (s444), white hake (s447), and Greenland halibut (s892) are related to the second and third trends. No species is associated with all three trends.

3.2.3 Choice of the explanatory variable

The estimated regression parameters for the explanatory variable are presented in Table 2A. The values of the *t* statistic indicate that the volume of CIL water below 0°C is significantly related (at a level of 5%) to thorny skate (s90), Atlantic cod (s438), silver hake (s449), and sandlance (s696).

3.3 Mean number per tow

3.3.1 Trends and model fits

The same 21 models were applied to the abundance data expressed in mean number per tow. Based on the AIC criterion, the model selected (12) was also characterized by three common trends and one explanatory variable: the volume of CIL water below 0°C (Table 1B).

The model's first trend presents little annual variation, with the exception of a decrease in 1992 and in 1993 and increases between 1999 and 2001 and in 2003 (Figure 6A). The model's second trend is characterized by a large increase between 1990 and 2007 followed by a slight decrease until 2009. The third trend is characterized by a sharp decrease between 1991 and 1992 followed by relatively stable values. The data fitted to the model are fairly consistent with the data observed (Figure 6B), and the residuals do not present any particular pattern (Figure 6C). However, the entire haddock (s441) time series is characterized by residuals of close to zero.

3.3.2 Loading factors

Spiny dogfish (s24), thorny skate (s90), smooth skate (s91), Atlantic cod (s438), longfin hake (s444), white hake (s447), American plaice (s889), witch flounder (s890), and Greenland halibut (s892) are positively related to the first trend, unlike spinytail skate (s102), pollock (s443), and winter flounder (s895) (Table 2B; Figure 7A). Atlantic halibut (s893) is positively related to the second trend (Table 2B; Figure 7B), while Atlantic cod (s438), haddock (s441), longfin hake (s444), white hake (s447), silver hake (s449), and redfish (s792) are positively related to the third trend (Figure 7C). Winter flounder (s895) is also negatively related to this trend. Black dogfish (s27), winter skate (s100), Atlantic herring (s150), sandlance (s696), and yellowtail flounder (s891) are not related to any of the trends. The series with the highest positive loading factors present annual variations similar to the corresponding trends (Figures 8A, 8B, and 8C).

Spiny dogfish (s24), thorny skate (s90), smooth skate (s91), spinytail skate (s102), pollock (s443), American plaice (s889), witch flounder (s890), and Greenland halibut (s892) are only associated with the first trend (Figure 5B). Atlantic halibut (s893) is only associated with the

second trend, while haddock (s441), silver hake (s449), and redfish (s792) are only associated with the third trend. Four species are associated with the first and third trends: Atlantic cod (s438), longfin hake (s444), white hake (s447), and winter flounder (s895).

3.3.3 Choice of the explanatory variable

The estimated regression parameters for the explanatory variable are presented in Table 2B. The values of the *t* statistics indicate that there is a significant relationship between the volume of CIF water below 0°C and thorny skate (s90), smooth skate (s91), and yellowtail flounder (s891).

3.4 Chronological clustering analysis

No cut-offs were observed with an alpha value of 0.01 for the abundance series expressed in mean weight per tow (Figure 9A). Two cut-offs (1991–1992 and 2002–2003) were observed for values of 0.05 and 0.1, three cut-offs (1991–1992, 1998–1999, and 2004–2005) for a value of 0.2, and one additional cut-off (2000–2001) at 0.3. For the abundance series expressed in mean number by tow, no cut-offs were observed for an alpha value of 0.01. One cut-off (1991–1992) was observed for 0.05, two cut-offs (1991–1992 and 2000–2001) for 0.1, and three cut-offs (1991–1992, 1994–1995, and 2000–2001) for 0.2 (Figure 9B). Lastly, two cut-offs (1991–1992 and 2000–2001) were observed for 0.3.

4. DISCUSSION

DFA is an objective approach that has allowed the identification of three common trends among a large group of time series abundance indices. As such, DFA figures among certain multivariate analyses (e.g., PCA, MDS) that are used to uncover significant signals in a reduced space. DFA has also identified the species that are linked to the common trends, that is, those that have presented the same abundance variations over the years. This overview is sometimes overlooked because the results of the multidisciplinary survey are only analyzed and interpreted for each species individually.

The first trend revealed by the mean weight per tow analysis shows significant differences (decrease and increase) starting in 2004 compared to the mean numbers per tow analysis (stability). These differences may be explained by the changes in catchability caused by the arrival of a new vessel in 2004, the CCGS *Teleost*. Although comparative fishing experiments were performed between the CCGS *Teleost* and the CCGS *Needler*, which had been used since 1990, calibrations were not performed for all species (Bourdages et al., 2007). Of the seven species linked to the first trend expressed in mean weight per tow, four (spiny dogfish, spinytail skate, silver hake, and sandlance) were not calibrated. However, most of the species linked to the two other trends were calibrated. These trends, expressed in mean weight per tow, are similar to those of mean numbers per tow.

DFA also revealed that the volume of CIL water below 0°C had an impact on some species; thus fluctuations in their abundance should not be interpreted as simply the result of commercial exploitation.

The chronological clustering analysis revealed a significant change of regime at the beginning of the 1990s. This change corresponds to a serious decline in many species (Bourdages et al., 2010; Bourdages and Ouellet, 2011). There was a second significant change at the end of the 1990s and the beginning of the 2000s. This period was characterized by an increase followed by a decline in several species.

The analysis techniques used in this study provide information on an ever-changing ecosystem. These techniques also reveal the complexities of this type of ecosystem once the main trends are identified. More in-depth studies could be performed using a greater number of species, only the most abundant species, or only the species for which catchability has been corrected.

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Table 1. Dynamic factor analysis models applied to the temporal series of abundance indices estimated in mean weight (kg) (A) and mean number (B) per tow from the multidisciplinary groundfish and shrimp research survey conducted annually in the Estuary and northern Gulf of St. Lawrence.

(A)	MODEL	COVARIANCE MATRIX R	NUMBER OF COMMON TRENDS	EXPLANATORY VARIABLES	AIC*
1	data= 1 common trend + noise	Diagonal	1	------	1124.84
2	data= M common trends + noise	Diagonal	1	------	1166.84
3	data= M common trends + noise	Diagonal	2	------	1119.63
4	data= M common trends + noise	Diagonal	3	------	1085.99
5	data= 1 common trend + explan. var. + noise	Diagonal	1	CIL mean temp. index	1128.22
6	data= M common trends + explan. var. + noise	Diagonal	1	CIL mean temp. index	1170.22
7	data= M common trends + explan. var. + noise	Diagonal	2	CIL mean temp. index	1124.09
8	data= M common trends + explan. var. + noise	Diagonal	3	CIL mean temp. index	1084.86
9	data= 1 common trend + explan. var. + noise	Diagonal	1	CIL vol. < 0 °C index	1134.45
10	data= M common trends + explan. var. + noise	Diagonal	1	CIL vol. < 0 °C index	1176.45
11	data= M common trends + explan. var. + noise	Diagonal	2	CIL vol. < 0 °C index	1119.81
12	data= M common trends + explan. var. + noise	Diagonal	3	CIL vol. < 0 °C index	1079.59**
13	data= 1 common trend + explan. var. + noise	Diagonal	1	CIL temp. + vol.	1132.78
14	data= M common trends + explan. var. + noise	Diagonal	1	CIL temp. + vol.	1174.78
15	data= M common trends + explan. var. + noise	Diagonal	2	CIL temp. + vol.	1130.75
16	data= M common trends + explan. var. + noise	Diagonal	3	CIL temp. + vol.	1098.95

(B)	MODEL	COVARIANCE MATRIX R	NUMBER OF COMMON TRENDS	EXPLANATORY VARIABLES	AIC*
1	data= 1 common trend + noise	Diagonal	1	------	1159.54
2	data= M common trends + noise	Diagonal	1	------	1201.54
3	data= M common trends + noise	Diagonal	2	------	1159.23
4	data= M common trends + noise	Diagonal	3	------	1115.16
5	data= 1 common trend + explan. var. + noise	Diagonal	1	CIL mean temp. index	1162.14
6	data= M common trends + explan. var. + noise	Diagonal	1	CIL mean temp. index	1204.13
7	data= M common trends + explan. var. + noise	Diagonal	2	CIL mean temp. index	1164.87
8	data= M common trends + explan. var. + noise	Diagonal	3	CIL mean temp. index	1115.59
9	data= 1 common trend + explan. var. + noise	Diagonal	1	CIL vol. < 0 °C index	1168.29
10	data= M common trends + explan. var. + noise	Diagonal	1	CIL vol. < 0 °C index	1210.30
11	data= M common trends + explan. var. + noise	Diagonal	2	CIL vol. < 0 °C index	1164.20
12	data= M common trends + explan. var. + noise	Diagonal	3	CIL vol. < 0 °C index	1110.61**
13	data= 1 common trend + explan. var. + noise	Diagonal	1	CIL temp. + vol.	1173.02
14	data= M common trends + explan. var. + noise	Diagonal	1	CIL temp. + vol.	1215.06
15	data= M common trends + explan. var. + noise	Diagonal	2	CIL temp. + vol.	1181.06
16	data= M common trends + explan. var. + noise	Diagonal	3	CIL temp. + vol.	1130.03

* Akaike information criterion

** Final model

Table 2. Estimated loading factors and regression parameters, standard errors, and t-values of the dynamic factor analysis models applied to the temporal series of abundance indices estimated in mean weight (kg) (A) and mean number (B) per tow from the multidisciplinary groundfish and shrimp research survey conducted annually in the Estuary and northern Gulf of St. Lawrence.

SPECIES	CODE	LOADING FACTORS			EXPLANATORY VARIABLE			
(A)		TREND 1	TREND 2	TREND 3	VOLUME CIL < 0°C (km^3)			
					Estimated values	S.E.	t-values	
Spiny dogfish (*Squalus acanthias*)	s24	**0.221**	0.113	-0.031	-0.280	0.205	-1.364	
Black dogfish (*Centroscyllium fabricii*)	s27	0.024	-0.190	0.107	-0.072	0.217	-0.333	
Thorny skate (*Amblyraja radiata*)	s90	-0.164	**0.981**	-0.011	0.575	0.207	2.775	*
Smooth skate (*Malacoraja senta*)	s91	**0.217**	**0.805**	-0.116	0.405	0.225	1.798	
Winter skate (*Leucoraja ocellata*)	s100	0.093	**0.326**	-0.089	-0.303	0.199	-1.520	
Spinytail skate (*Bathyraja spinicauda*)	s102	**-0.542**	-0.080	0.017	-0.030	0.107	-0.276	
Atlantic herring (*Clupea harengus harengus*)	s150	**-0.316**	-0.088	0.042	-0.251	0.181	-1.387	
Atlantic cod (*Gadus morhua*)	s438	0.001	**0.937**	0.198	0.455	0.193	2.361	*
Haddock (*Melanogrammus aeglefinus*)	s441	-0.021	**0.506**	**0.349**	0.239	0.142	1.686	
Pollock (*Pollachius virens*)	s443	-0.001	**-0.433**	0.193	-0.102	0.205	-0.497	
Longfin hake (*Urophycis chesteri*)	s444	0.083	**0.409**	**0.344**	0.041	0.143	0.289	
White hake (*Urophycis tenuis*)	s447	0.090	**0.420**	**0.322**	-0.087	0.160	-0.548	
Silver hake (*Merluccius bilinearis*)	s449	**-0.331**	0.122	0.011	0.513	0.177	2.903	*
Sandlance (*Ammodytes* spp.)	s696	**0.232**	0.196	0.054	-0.475	0.188	-2.519	*
Redfish (*Sebastes* spp.)	s792	-0.107	0.147	**0.435**	0.058	0.115	0.506	
American plaice (*Hippoglossoides platessoides*)	s889	0.092	**0.908**	-0.063	0.379	0.230	1.646	
Witch flounder (*Glyptocephalus cynoglossus*)	s890	0.098	**0.768**	0.193	0.064	0.201	0.317	
Yellowtail flounder (*Limanda ferruginea*)	s891	-0.155	**0.217**	0.024	-0.323	0.188	-1.721	
Greenland halibut (*Reinhardtius hippoglossoides*)	s892	-0.120	**0.580**	**-0.240**	0.184	0.175	1.051	
Atlantic halibut (*Hippoglossus hippoglossus*)	s893	**-0.427**	0.043	-0.048	0.269	0.155	1.737	
Winter flounder (*Pseudopleuronectes americanus*)	s895	0.044	**-0.350**	-0.049	0.322	0.199	1.619	

* Significant at the 5% level

SPECIES	CODE	LOADING FACTORS			EXPLANATORY VARIABLE			
(B)		TREND 1	TREND 2	TREND 3	VOLUME CIL < 0°C (km^3)			
					Estimated values	S.E.	t-values	
Spiny dogfish (*Squalus acanthias*)	s24	**0.561**	-0.180	-0.094	-0.073	0.201	-0.364	
Black dogfish (*Centroscyllium fabricii*)	s27	0.074	-0.079	-0.025	0.038	0.216	0.177	
Thorny skate (*Amblyraja radiata*)	s90	**0.754**	0.053	0.126	0.646	0.213	3.035	*
Smooth skate (*Malacoraja senta*)	s91	**0.826**	0.156	-0.086	0.538	0.203	2.642	*
Winter skate (*Leucoraja ocellata*)	s100	0.188	-0.056	-0.171	-0.243	0.209	-1.166	
Spinytail skate (*Bathyraja spinicauda*)	s102	**-0.231**	0.164	0.079	-0.216	0.187	-1.154	
Atlantic herring (*Clupea harengus harengus*)	s150	-0.011	0.104	0.003	-0.265	0.193	-1.368	
Atlantic cod (*Gadus morhua*)	s438	**0.397**	0.025	**0.512**	0.352	0.173	2.039	
Haddock (*Melanogrammus aeglefinus*)	s441	0.184	-0.018	**0.676**	0.060	0.136	0.443	
Pollock (*Pollachius virens*)	s443	**-0.373**	-0.095	0.051	0.169	0.190	0.890	
Longfin hake (*Urophycis chesteri*)	s444	**0.619**	-0.162	**0.342**	-0.138	0.171	-0.805	
White hake (*Urophycis tenuis*)	s447	**0.609**	-0.132	**0.385**	-0.101	0.177	-0.571	
Silver hake (*Merluccius bilinearis*)	s449	0.055	0.182	**0.321**	0.182	0.191	0.953	
Sandlance (*Ammodytes* spp.)	s696	0.110	-0.083	-0.124	-0.244	0.212	-1.152	
Redfish (*Sebastes* spp.)	s792	0.045	0.065	**0.648**	-0.067	0.168	-0.397	
American plaice (*Hippoglossoides platessoides*)	s889	**1.070**	-0.012	-0.069	0.443	0.239	1.851	
Witch flounder (*Glyptocephalus cynoglossus*)	s890	**1.205**	-0.052	0.174	0.285	0.238	1.197	
Yellowtail flounder (*Limanda ferruginea*)	s891	-0.033	0.043	0.000	-0.465	0.190	-2.455	*
Greenland halibut (*Reinhardtius hippoglossoides*)	s892	**0.776**	0.140	-0.125	0.161	0.191	0.843	
Atlantic halibut (*Hippoglossus hippoglossus*)	s893	-0.035	**0.315**	0.140	0.080	0.094	0.851	
Winter flounder (*Pseudopleuronectes americanus*)	s895	**-0.247**	-0.092	**-0.208**	0.338	0.188	1.799	

* Significant at the 5% level

Note: Loading factors greater than an arbitrary cutoff level of 0.2 (in absolute value) are in bold and underlined

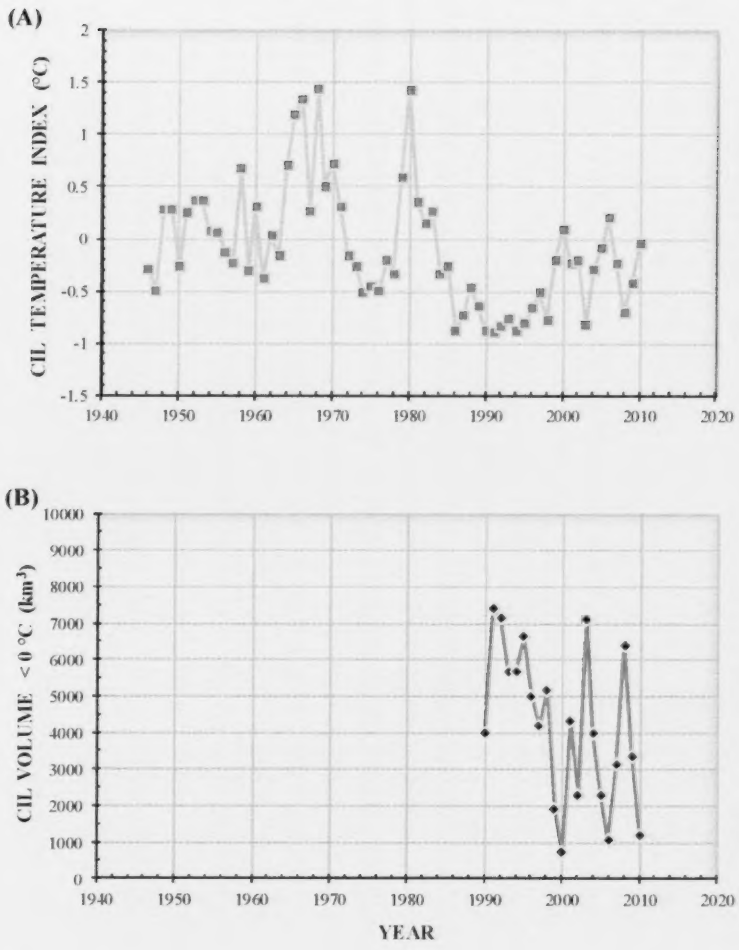


Figure 1. Cold intermediate layer (CIL) temperature (°C) index (A) and volume (km^3) of the CIL with temperatures below 0°C (B). Both time series were standardized before the analysis.

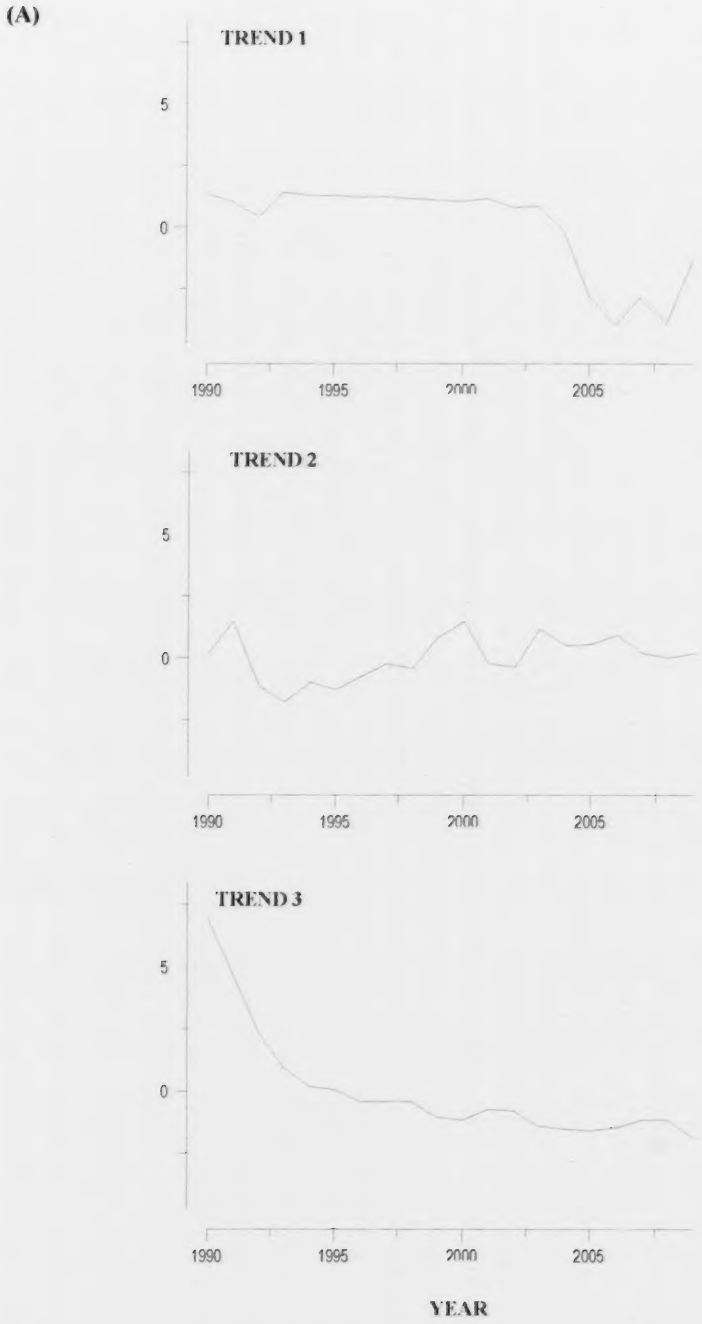
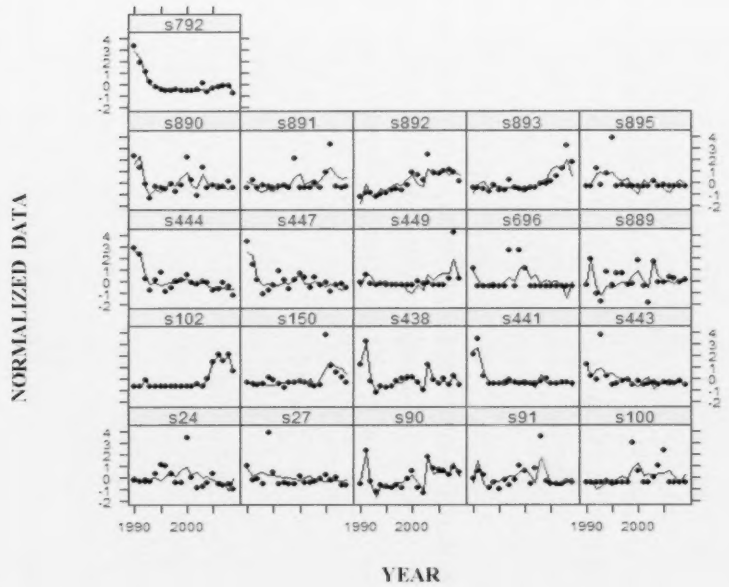


Figure 2. Common trends (A), observed data and fitted values (B), and residuals (C) obtained by the final DFA model applied to the temporal series of abundance indices (mean weight per tow) estimated from the multidisciplinary groundfish and shrimp research survey conducted annually in the Estuary and northern Gulf of St. Lawrence (see Table 2 for species codes).

(B)



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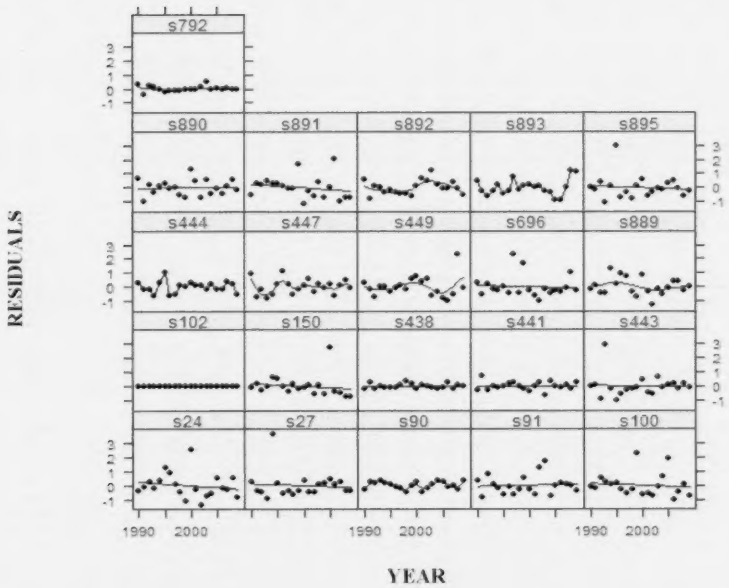


Figure 2. (Continued).

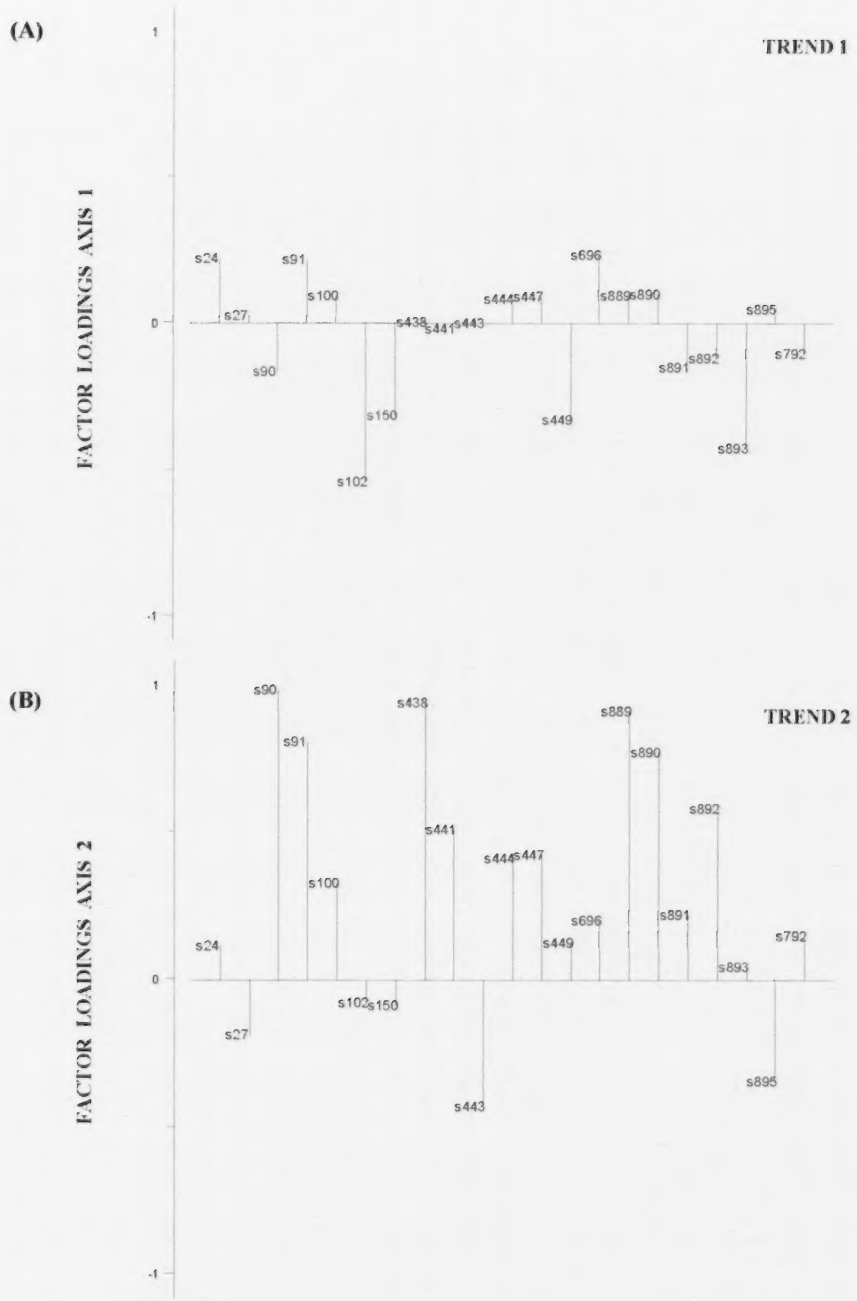


Figure 3. Loading factors for each trend (A: trend 1, B: trend 2, and C: trend 3) from the final DFA model applied to the temporal series of abundance indices (mean weight per tow) estimated from the multidisciplinary groundfish and shrimp research survey conducted annually in the Estuary and northern Gulf of St. Lawrence (see Table 2 for species codes).

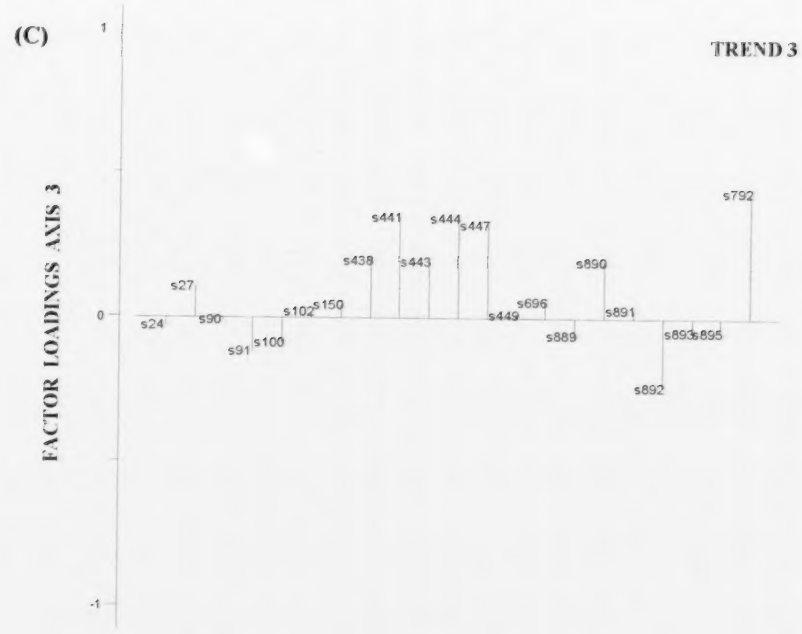


Figure 3. (Continued).

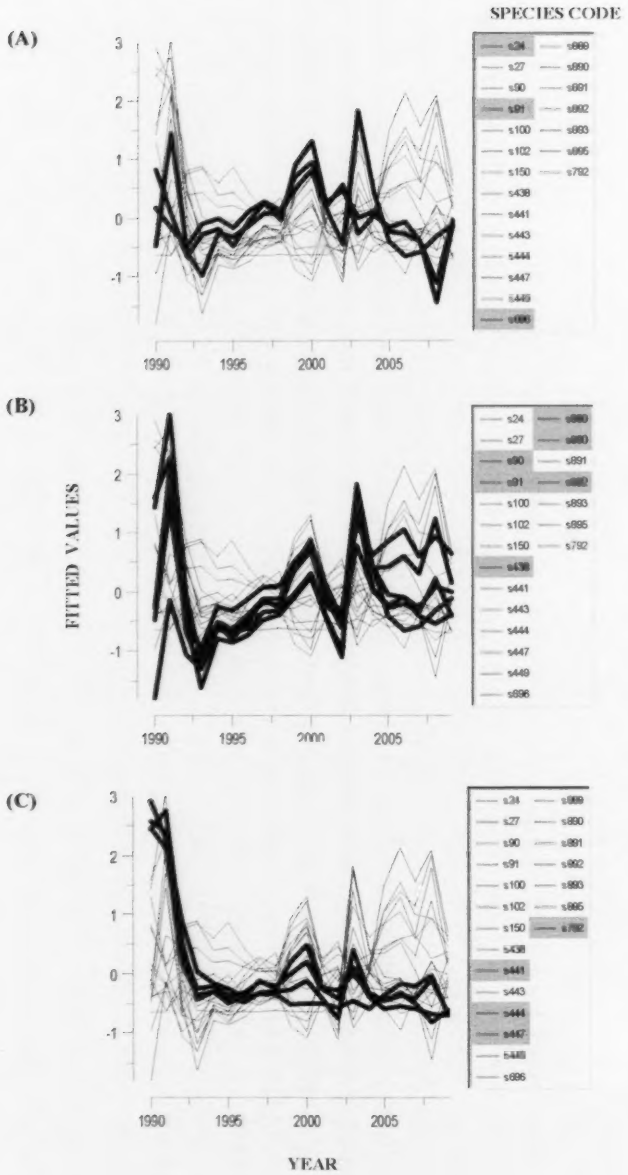


Figure 4. Fitted values from the final DFA model applied to the temporal series of abundance indices (mean weight per tow) estimated from the multidisciplinary groundfish and shrimp research survey conducted annually in the Estuary and northern Gulf of St. Lawrence. For each trend, the thick lines correspond to the species with the highest positive loading factors. These species are: (A) trend 1: spiny dogfish (s24), smooth skate (s91), and sandlance (s696); (B) trend 2: thorny skate (s90), smooth skate (s91), Atlantic cod (s438), American plaice (s889), witch flounder (s890), and Greenland halibut (s892); (C) trend 3: haddock (s441), longfin hake (s444), white hake (s447), and redfish (s792).

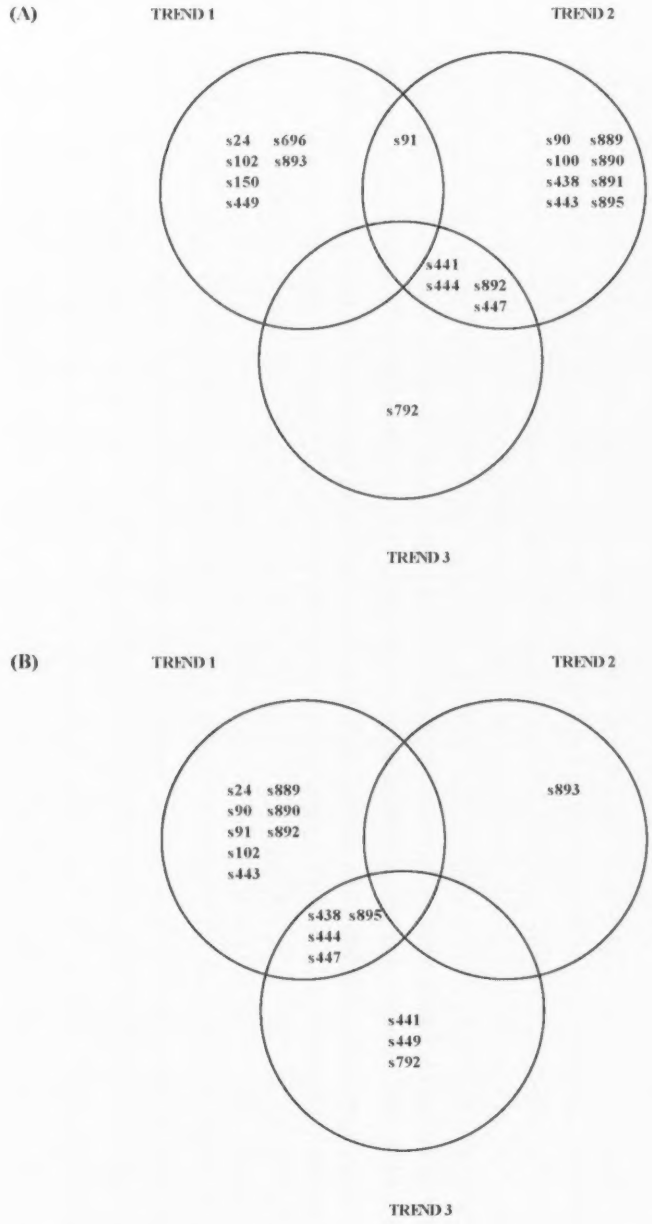


Figure 5. Venn diagrams of the loading factors for the mean weight (kg) (A) and mean number (B) per tow. Loading factors smaller than 0.2 (absolute value) are not plotted (see Table 2 for species codes).

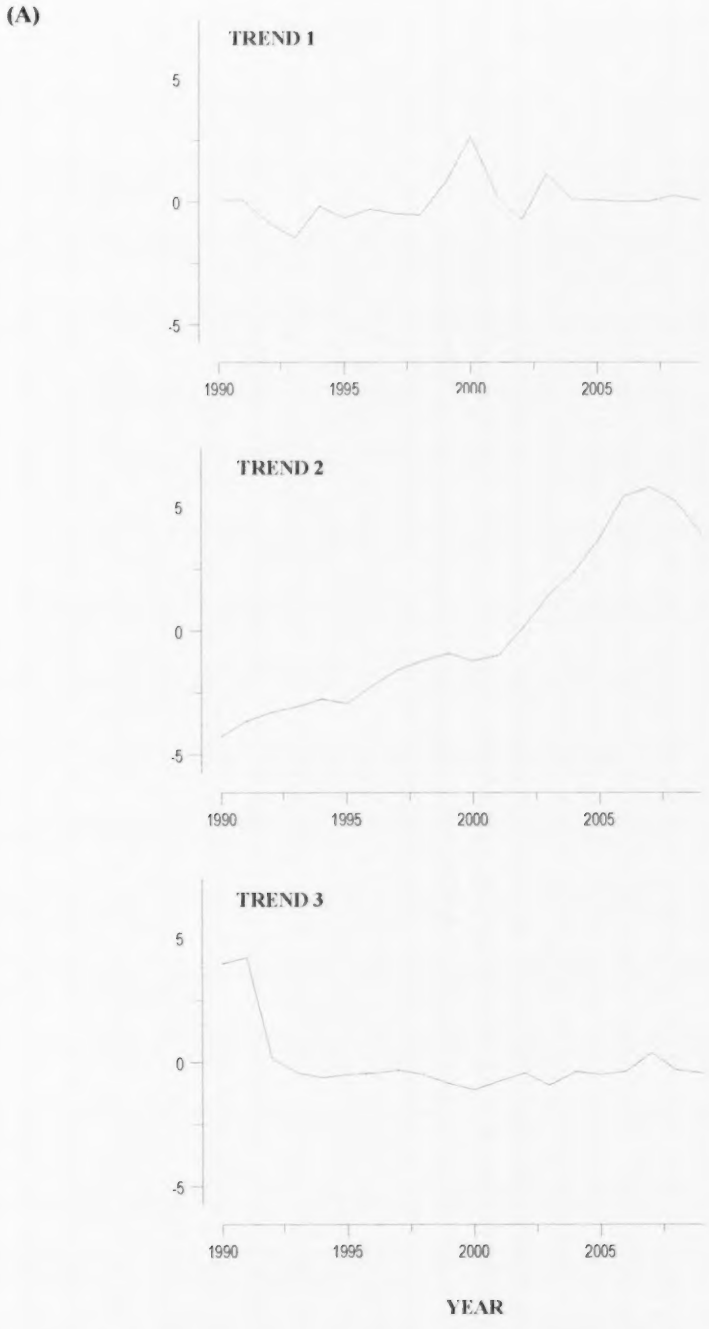
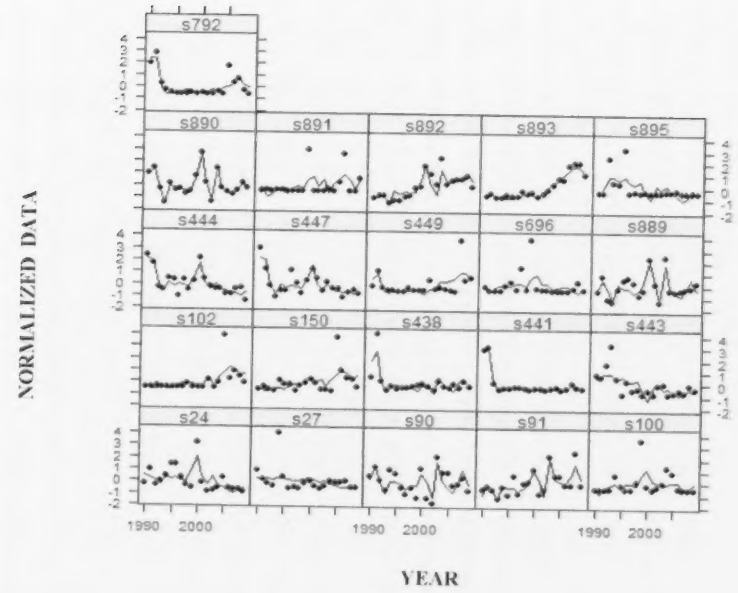


Figure 6. Common trends (A), observed data and fitted values (B), and residuals (C) obtained by the final DFA model applied to the temporal series of abundance indices (mean number per tow) estimated from the multidisciplinary groundfish and shrimp research survey conducted annually in the Estuary and northern Gulf of St. Lawrence (see Table 2 for species codes).

(B)



(C)

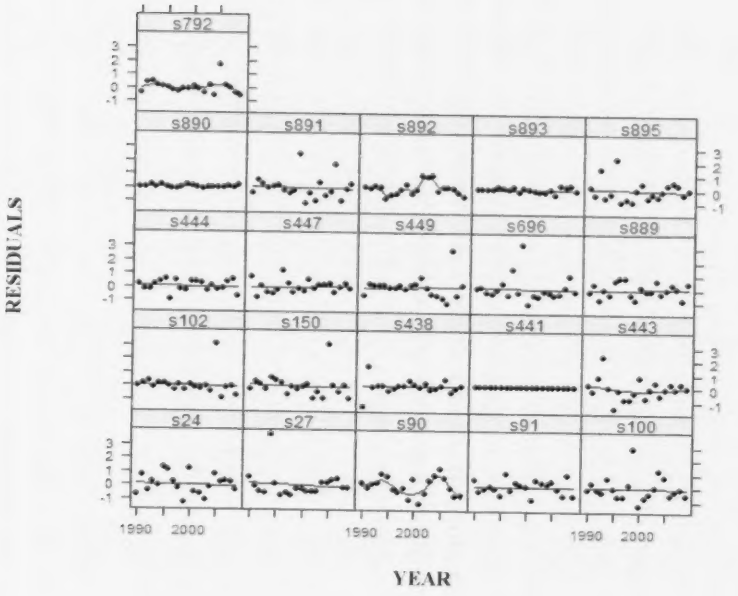


Figure 6. (Continued).

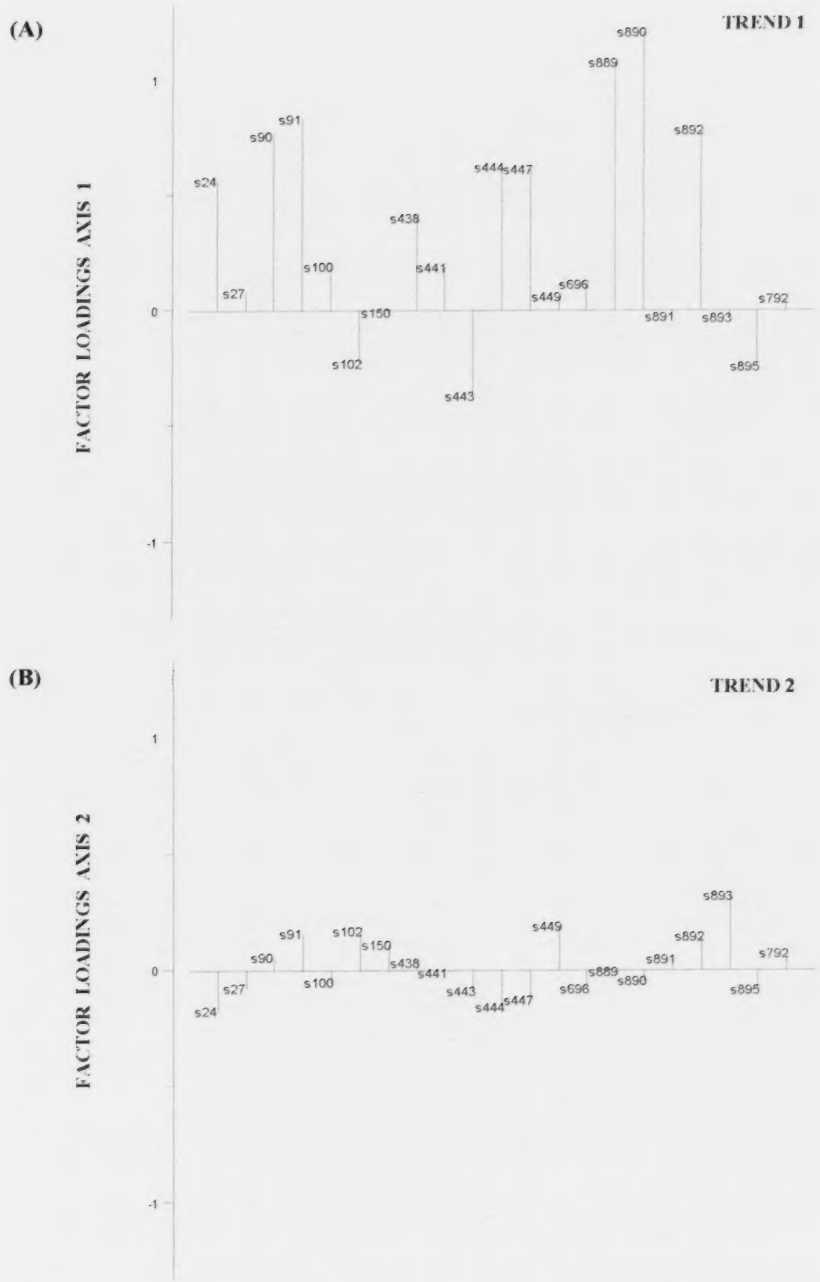


Figure 7. Loading factors for each trend (A: trend 1, B: trend 2, and C: trend 3) from the final DFA model applied to the temporal series of abundance indices (mean number per tow) estimated from the multidisciplinary groundfish and shrimp research survey conducted annually in the Estuary and northern Gulf of St. Lawrence (see Table 2 for species codes).

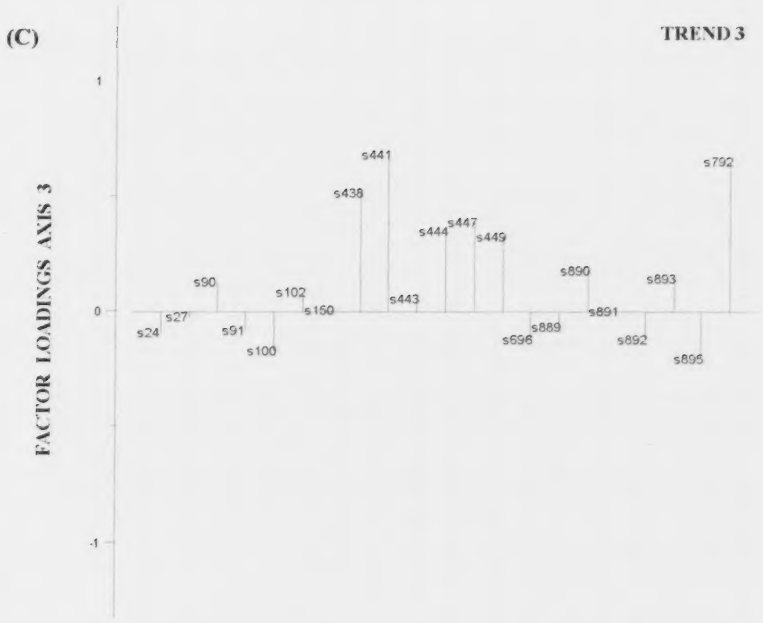


Figure 7. (Continued).

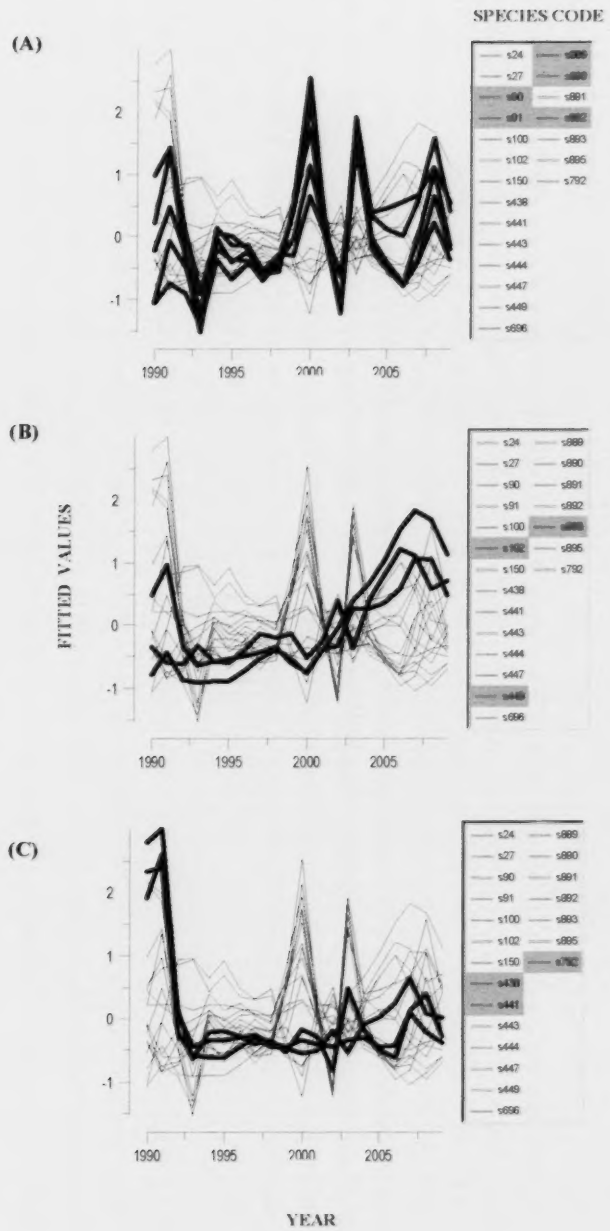
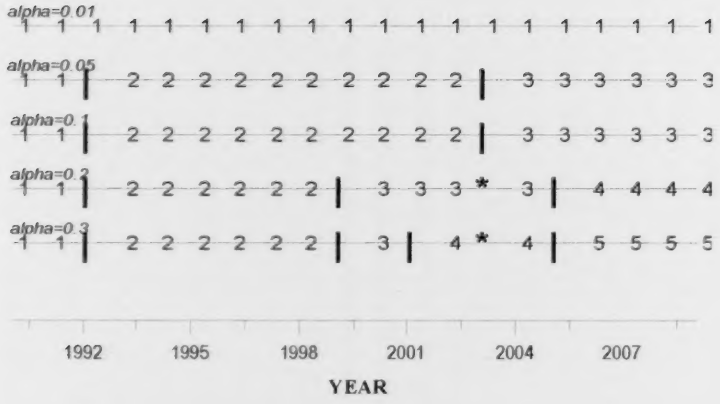


Figure 8. Fitted values from the final DFA model applied to the temporal series of abundance indices (mean number per tow) estimated from the multidisciplinary groundfish and shrimp research survey conducted annually in the Estuary and northern Gulf of St. Lawrence. For each trend, the thick lines correspond to the species with the highest positive loading factors. These species are: (A) trend 1: thorny skate (s90), smooth skate (s91), American plaice (s889), witch flounder (s890), and Greenland halibut (s892); (B) trend 2: spinytail skate (s102), silver hake (s449), and Atlantic halibut (s893); (C) trend 3: Atlantic cod (s438), haddock (s441), and redfish (s792).

(A)



(B)

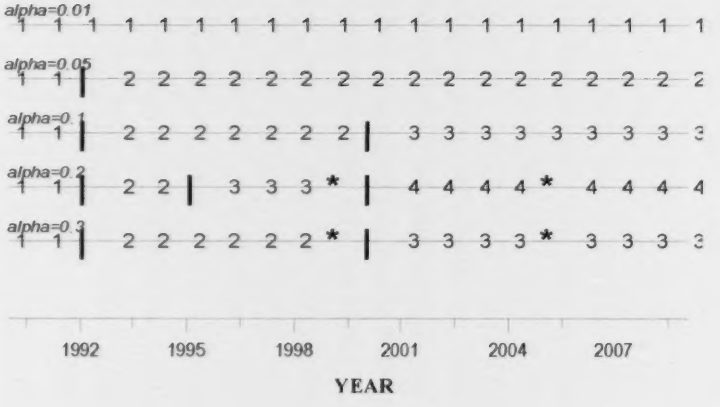


Figure 9. Results of the chronological clustering analysis applied to the temporal series of abundance indices in mean weight (kg) (A) and mean number (B) per tow estimated from the multidisciplinary groundfish and shrimp research survey conducted annually in the Estuary and northern Gulf of St. Lawrence. Vertical lines correspond to the start of a new group, numbers refer to groups, and stars are so-called singletons (a singleton is a point that does not belong to the group immediately before or after it). The smallest alpha value gives the most important breakpoints.

Appendix 1. Abundance indices in mean weight (kg) per tow from the multidisciplinary groundfish and shrimp research survey conducted annually in the Estuary and northern Gulf of St. Lawrence. CIL temperature (°C) index and volume (km^3) of water < 0°C are also indicated.

SPECIES	CODE	YEAR											
		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Spiny dogfish (*Squalus acanthias*)	s24	0.063	0.056	0.059	0.054	0.106	0.168	0.159	0.110	0.045	0.042	0.361	0.078
Black dogfish (*Centroscyllium fabricii*)	s27	9.746	2.904	3.843	1.207	25.301	6.429	1.335	2.022	0.908	1.229	4.595	1.562
Thorny skate (*Amblyraja radiata*)	s90	3.007	7.189	3.327	2.013	2.935	2.633	2.547	2.822	2.597	3.623	4.575	2.471
Smooth skate (*Malacoraja senta*)	s91	1.262	2.219	1.683	0.275	0.863	0.233	1.165	0.632	1.217	2.747	2.113	0.709
Winter skate (*Leucoraja ocellata*)	s100	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.037	0.011	0.000
Spinytail skate (*Bathyraja spinicauda*)	s102	0.000	0.000	0.022	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Atlantic herring (*Clupea harengus harengus*)	s150	0.809	0.597	0.386	0.611	1.387	1.086	0.556	0.191	0.805	0.723	0.893	0.777
Atlantic cod (*Gadus morhua*)	s438	37.221	63.904	18.069	4.755	12.148	10.130	11.590	17.683	21.462	22.684	22.148	16.396
Haddock (*Melanogrammus aeglefinus*)	s441	0.078	0.119	0.021	0.000	0.001	0.001	0.005	0.012	0.006	0.000	0.000	0.002
Pollock (*Pollachius virens*)	s443	0.097	0.041	0.025	0.236	0.041	0.000	0.009	0.017	0.024	0.000	0.018	0.000
Longfin hake (*Urophycis chesteri*)	s444	1.453	1.289	0.682	0.370	0.648	0.817	0.345	0.433	0.591	0.628	0.773	0.586
White hake (*Urophycis tenuis*)	s447	4.135	2.586	1.517	0.595	0.878	1.223	2.118	1.535	0.893	1.536	1.944	1.731
Silver hake (*Merluccius bilinearis*)	s449	0.016	0.055	0.010	0.003	0.011	0.000	0.000	0.005	0.002	0.003	0.005	0.023
Sandlance (*Ammodytes* spp.)	s696	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.002	0.001	0.000
Redfish (*Sebastes* spp.)	s792	168.572	112.768	83.917	46.771	28.085	18.938	15.434	17.842	18.735	14.714	17.306	15.347
American plaice (*Hippoglossoides platessoides*)	s889	3.899	7.737	2.621	1.444	5.872	3.814	5.581	5.651	3.829	4.006	7.509	3.732
Witch flounder (*Glyptocephalus cynoglossus*)	s890	3.515	2.693	1.570	0.565	1.342	1.232	1.188	1.539	1.033	1.433	3.436	1.839
Yellowtail flounder (*Limanda ferruginea*)	s891	0.000	0.021	0.000	0.008	0.005	0.000	0.004	0.007	0.001	0.083	0.001	0.000
Greenland halibut (*Reinhardtius hippoglossoides*)	s892	4.346	7.612	7.882	3.985	7.231	8.604	10.818	11.764	11.269	16.963	30.017	27.361
Atlantic halibut (*Hippoglossus hippoglossus*)	s893	0.292	0.282	0.179	0.025	0.485	0.054	0.120	0.847	0.244	0.211	0.177	0.280
Winter flounder (*Pseudopleuronectes americanus*)	s895	0.000	0.000	0.018	0.002	0.013	0.049	0.001	0.002	0.000	0.000	0.000	0.000
CIL temperature (°C) index		-0.88	-0.89	-0.83	-0.75	-0.87	-0.80	-0.65	-0.51	-0.77	-0.20	0.10	-0.23
Volume CIL < 0°C (km^3)		3972.9	7388.3	7137.2	5681.4	5688.9	6639.2	5016.7	4175.0	5169.4	1928.3	721.7	4342.4

Appendix 1. (Continued).

SPECIES	CODE	YEAR							
		2002	2003	2004	2005	2006	2007	2008	2009
Spiny dogfish (*Squalus acanthias*)	s24	0.004	0.020	0.042	0.107	0.038	0.022	0.030	0.000
Black dogfish (*Centroscyllium fabricii*)	s27	1.693	2.381	3.773	5.263	2.961	4.303	0.522	0.882
Thorny skate (*Amblyraja radiata*)	s90	1.917	6.457	4.892	4.811	4.574	4.175	5.084	4.514
Smooth skate (*Malacoraja senta*)	s91	2.395	5.931	1.008	0.818	0.793	0.718	1.022	0.837
Winter skate (*Leucoraja ocellata*)	s100	0.000	0.005	0.015	0.029	0.000	0.000	0.000	0.000
Spinytail skate (*Bathyraja spinicauda*)	s102	0.010	0.000	0.030	0.092	0.119	0.094	0.117	0.057
Atlantic herring (*Clupea harengus harengus*)	s150	0.381	0.228	0.439	6.378	2.701	1.920	1.351	0.701
Atlantic cod (*Gadus morhua*)	s438	7.867	37.144	18.800	15.647	21.392	13.554	23.972	14.421
Haddock (*Melanogrammus aeglefinus*)	s441	0.000	0.007	0.014	0.000	0.001	0.005	0.005	0.002
Pollock (*Pollachius virens*)	s443	0.006	0.013	0.000	0.010	0.014	0.005	0.020	0.003
Longfin hake (*Urophycis chesteri*)	s444	0.525	0.592	0.582	0.383	0.413	0.571	0.482	0.260
White hake (*Urophycis tenuis*)	s447	0.988	1.682	1.179	1.333	0.748	1.171	1.253	0.980
Silver hake (*Merluccius bilinearis*)	s449	0.007	0.016	0.005	0.004	0.000	0.032	0.269	0.033
Sandlance (*Ammodytes* spp.)	s696	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Redfish (*Sebastes* spp.)	s792	20.588	40.003	10.611	24.651	30.877	31.944	34.542	8.437
American plaice (*Hippoglossoides platessoides*)	s889	1.162	7.342	4.322	4.376	5.020	4.830	4.193	4.633
Witch flounder (*Glyptocephalus cynoglossus*)	s890	0.717	2.736	1.290	1.443	1.232	1.397	1.685	1.221
Yellowtail flounder (*Limanda ferruginea*)	s891	0.000	0.017	0.000	0.043	0.122	0.006	0.002	0.005
Greenland halibut (*Reinhardtius hippoglossoides*)	s892	21.602	49.836	30.886	29.315	31.777	33.026	31.187	21.300
Atlantic halibut (*Hippoglossus hippoglossus*)	s893	0.267	0.526	0.535	0.750	1.064	1.623	3.267	2.059
Winter flounder (*Pseudopleuronectes americanus*)	s895	0.000	0.006	0.001	0.002	0.000	0.000	0.000	0.000
CIL temperature (°C) index		-0.20	-0.82	-0.28	-0.08	0.21	-0.23	-0.70	-0.42
Volume CIL < 0°C (km^3)		2296.3	7113.8	3996.3	2297.9	1061.5	3156.0	6395.4	3359.4

Appendix 2. Abundance indices in mean number per tow from the multidisciplinary groundfish and shrimp research survey conducted annually in the Estuary and northern Gulf of St. Lawrence.

SPECIES	CODE	YEAR											
		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Spiny dogfish (*Squalus acanthias*)	s24	0.034	0.096	0.029	0.045	0.067	0.122	0.119	0.065	0.031	0.022	0.214	0.043
Black dogfish (*Centroscyllium fabricii*)	s27	11.881	6.484	4.370	2.738	34.476	8.155	1.839	2.222	1.060	4.471	5.824	2.856
Thorny skate (*Amblyraja radiata*)	s90	9.222	10.912	8.666	6.557	10.398	9.892	7.190	5.932	7.168	5.217	10.813	5.287
Smooth skate (*Malacoraja senta*)	s91	3.035	3.373	2.923	1.219	3.579	1.947	5.740	2.168	4.157	4.510	7.064	2.334
Winter skate (*Leucoraja ocellata*)	s100	0.000	0.000	0.000	0.000	0.023	0.006	0.000	0.000	0.013	0.074	0.007	0.000
Spinytail skate (*Bathyraja spinicauda*)	s102	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000
Atlantic herring (*Clupea harengus harengus*)	s150	2.100	3.196	2.432	1.729	6.713	4.765	4.859	1.384	4.073	5.524	7.107	5.513
Atlantic cod (*Gadus morhua*)	s438	69.219	279.489	50.782	9.747	31.845	13.731	19.633	24.655	27.396	35.176	39.205	26.471
Haddock (*Melanogrammus aeglefinus*)	s441	0.212	0.226	0.036	0.000	0.007	0.008	0.011	0.013	0.005	0.000	0.007	0.003
Pollock (*Pollachius virens*)	s443	0.025	0.021	0.038	0.064	0.020	0.000	0.016	0.005	0.006	0.000	0.005	0.000
Longfin hake (*Urophycis chesteri*)	s444	10.950	9.305	4.554	4.046	6.234	5.941	2.720	6.130	3.821	5.783	10.350	6.317
White hake (*Urophycis tenuis*)	s447	8.031	5.203	3.065	1.356	2.320	2.376	5.083	3.326	1.886	3.714	5.239	4.074
Silver hake (*Merluccius bilinearis*)	s449	0.051	0.203	0.045	0.009	0.021	0.000	0.000	0.035	0.009	0.010	0.015	0.110
Sandlance (*Ammodytes* spp.)	s696	0.048	0.000	0.000	0.000	0.065	0.122	0.015	0.300	0.020	0.643	0.037	0.023
Redfish (*Sebastes* spp.)	s792	1047.050	1359.367	369.576	160.471	75.009	50.453	45.001	54.258	99.657	72.957	104.163	71.996
American plaice (*Hippoglossoides platessoides*)	s889	40.249	78.910	21.631	15.333	47.145	69.996	76.489	62.217	30.309	43.329	124.109	59.381
Witch flounder (*Glyptocephalus cynoglossus*)	s890	22.050	24.936	14.301	6.585	16.724	13.085	13.848	11.623	12.482	20.531	32.439	17.310
Yellowtail flounder (*Limanda ferruginea*)	s891	0.000	0.049	0.000	0.029	0.032	0.000	0.017	0.010	0.005	1.120	0.003	0.000
Greenland halibut (*Reinhardtius hippoglossoides*)	s892	26.236	37.635	35.953	12.106	20.467	18.768	31.396	38.283	61.680	68.384	136.683	113.671
Atlantic halibut (*Hippoglossus hippoglossus*)	s893	0.021	0.061	0.006	0.002	0.034	0.018	0.024	0.080	0.049	0.073	0.025	0.051
Winter flounder (*Pseudopleuronectes americanus*)	s895	0.001	0.001	0.122	0.034	0.032	0.151	0.001	0.003	0.000	0.003	0.000	0.000

Appendix 2. (Continued).

SPECIES	CODE	YEAR							
		2002	2003	2004	2005	2006	2007	2008	2009
Spiny dogfish (*Squalus acanthias*)	s24	0.003	0.010	0.021	0.063	0.017	0.011	0.016	0.000
Black dogfish (*Centroscyllium fabricii*)	s27	1.843	2.580	5.942	5.108	5.272	6.021	1.900	2.202
Thorny skate (*Amblyraja radiata*)	s90	4.311	12.837	10.087	10.014	7.687	7.792	8.973	6.518
Smooth skate (*Malacoraja senta*)	s91	3.083	9.600	5.615	5.624	4.053	4.071	10.211	3.906
Winter skate (*Leucoraja ocellata*)	s100	0.005	0.010	0.033	0.026	0.002	0.000	0.000	0.000
Spinytail skate (*Bathyraja spinicauda*)	s102	0.014	0.000	0.009	0.100	0.017	0.032	0.022	0.010
Atlantic herring (*Clupea harengus harengus*)	s150	2.202	2.036	1.889	27.052	11.373	7.392	7.374	3.328
Atlantic cod (*Gadus morhua*)	s438	11.038	54.280	26.681	20.158	38.278	25.302	55.686	29.178
Haddock (*Melanogrammus aeglefinus*)	s441	0.000	0.007	0.010	0.001	0.002	0.037	0.016	0.005
Pollock (*Pollachius virens*)	s443	0.012	0.014	0.000	0.002	0.005	0.001	0.011	0.006
Longfin hake (*Urophycis chesteri*)	s444	4.718	4.297	4.317	3.183	3.103	4.319	4.334	1.947
White hake (*Urophycis tenuis*)	s447	2.254	3.446	2.727	2.712	1.355	2.196	2.427	1.989
Silver hake (*Merluccius bilinearis*)	s449	0.026	0.045	0.025	0.012	0.000	0.505	0.119	0.137
Sandlance (*Ammodytes* spp.)	s696	0.017	0.000	0.004	0.000	0.009	0.030	0.121	0.020
Redfish (*Sebastes* spp.)	s792	68.564	146.246	46.167	949.715	437.713	528.952	174.418	65.469
American plaice (*Hippoglossoides platessoides*)	s889	14.590	129.155	43.573	40.434	43.480	45.970	49.734	63.042
Witch flounder (*Glyptocephalus cynoglossus*)	s890	7.510	24.868	14.491	12.468	10.997	13.647	17.589	14.470
Yellowtail flounder (*Limanda ferruginea*)	s891	0.000	0.087	0.004	0.245	1.016	0.021	0.019	0.356
Greenland halibut (*Reinhardtius hippoglossoides*)	s892	77.343	162.719	75.543	90.425	92.994	95.539	101.723	67.603
Atlantic halibut (*Hippoglossus hippoglossus*)	s893	0.098	0.163	0.229	0.220	0.379	0.418	0.407	0.271
Winter flounder (*Pseudopleuronectes americanus*)	s895	0.000	0.006	0.003	0.007	0.000	0.000	0.000	0.000